THE EFFECTS OF NODALITY ON THE FORMATION OF EQUIVALENCE CLASSES

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A four-member equivalence class (A → B → C → D) can be formed by training AB, BC, and CD. The nodal stimuli, B and C, mediate all of the derivative (transitive and equivalence) relations in the class. The derivative relations AC, CA, BD, and DB are separated by one node, whereas AD and DA are separated by two nodes. How do the number of nodes that separate the stimuli in a derivative relation influence the induction of stimulus control exerted by that relation? Seven college students learned two four-member classes made up of nonsense syllables. After training, all derivative relations were presented repeatedly without informative feedback. Stimulus control exerted by each derivative relation was assessed concurrently. For the 7 subjects, control exerted by the derivative relations increased gradually with repeated presentations. With 6 of the 7 subjects, the one-node relations exerted more control than the two-node relations during the process. However, the disparity between the one- and two-node relations decreased with repeated presentations. Eventually, all derivative relations exerted complete control. The control exerted by derivative relations during induction was inversely related to the number of nodes separating the terms in the derivative relations. These results demonstrate that nodal distance is a determinant of the relatedness of stimuli in equivalence classes. The findings are discussed in terms of remote association, semantic memory networks, and the study of transitive inference.

Key words: equivalence class, intervening nodes, derivative relations, remote associations, semantic memory networks, associative distance, nonsense syllables, computer keyboard input, college students

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An equivalence class consists of a group of stimuli, all of which become interrelated even though they do not necessarily share any common physical properties (Sidman, 1971). An example of such a class drawn from the realm of organic chemistry consists of the four representations of ethanol: C_2H_5OH, grain alcohol, liquor, and ethanol. To create a class from a group of N such disparate stimuli, $(N - 1)$ stimulus–stimulus relations must be established by training, with the proviso that each stimulus is used in at least one of the stimulus–stimulus relations (Fields, Verhave, & Fath, 1984). In addition, two different stimuli must be used in each training relation.

If the four stimuli in the group are identified

by the letters A, B, C, and D, one way to establish the class is to train the two-term relations AB, BC, and CD, each of which is represented by one of the arrows above the stimulus letters in Figure 1. Each two-term relation is established on a trial-by-trial basis using the conditional discrimination paradigm. For example, during AB training, A is presented as a sample with B as a positive comparison and an unrelated new stimulus (X) as a negative comparison. The choice of B is reinforced. Similar training is conducted with BC and CD. If a class has been established, all of the stimuli have become interrelated. Thus, many new stimulus–stimulus relations are formed. The terms in each such relation will be identified as being related by a subject even though they have never been presented together previously (Fields & Verhave, 1987; Sidman & Tailby, 1982). Each of these emergent two-term relations is represented by one of the lines beneath the letters in Figure 1. There are four types of emergent relations: reflexive (AA, BB, CC, DD), symmetrical (BA, CB, DC), transitive (AC, BD, AD), and equivalence (DB, CA, DA) (Bush,

Letter-Line Array				Two-Term Relations Sa-Co+	Type	Intervening Nodes
-------->				A-B	Training	
	-------->			B-C	Training	
		-------->		C-D	Training	
A	B	C	D		STIMULI IN CLASS	
<->				A-A	Reflexive	
	<->			B-B	Reflexive	
		<->		C-C	Reflexive	
			<->	D-D	Reflexive	
		<--------		D-C	Symmetrical	
	<--------			C-B	Symmetrical	
<--------				B-A	Symmetrical	
-------(B)-----(C)------>				A-D	Derivative-T	2-node (B and C)
<------(B)-----(C)-------				D-A	Derivative-E	2-node (B and C)
	-------(C)------>			B-D	Derivative-T	1-node (C)
	<------(C)-------			D-B	Derivative-E	1-node (C)
-------(B)------>				A-C	Derivative-T	1-node (B)
<------(B)-------				C-A	Derivative-E	1-node (B)

Fig. 1. A letter-line array depicting a four-member equivalence class. The stimuli used to form the class are depicted as the letters A–D. All two-term relations used for training are depicted as arrows above the letters. The letter beneath the tail of the arrow indicates the sample, and the letter beneath the head of the arrow indicates the comparison. All emergent relations are depicted as arrows beneath the letters. Each arrow depicts a separate two-term relation. The letter designation of each two-term relation is listed to the right of the arrow. For emergent relations, the type of relation and the number of intervening nodes found in each derivative relation are also indicated. Derivative-T is a transitive relation. Derivative-E is an equivalence relation.

Sidman, & de Rose, 1989; Fields & Verhave, 1987). Equivalence relations have also been called combined transitive and symmetry relations. Taken together, transitive and equivalence relations have been called derivative relations (Fields & Verhave, 1987). Each derivative relation consists of two stimuli that are related by dint of linkage with another stimulus or a series of other stimuli through prior training. For example, C and A are linked by prior training with B. Control of behavior by an emergent relation is also assessed with the conditional discrimination paradigm. Thus, C would be presented as a sample with A as a positive comparison along with a stimulus from another class as the negative comparison. This is done without informative feedback. Choice of the positive comparison indicates that the CA relation exerts stimulus control. If all of the emergent relations control responding, the group of stimuli functions as an equivalence class (Sidman, Kirk, & Willson-Morris, 1985).

On a formal level, a derivative relation can be categorized by the number of intervening stimuli that mediate the two terms in such a relation. The intervening stimuli that link the terms in derivative relations are called nodes and are defined as stimuli that are linked by training to at least two other stimuli in the class (Fields et al., 1984). The four-member class (A → B → C → D) illustrated in Figure 1 contains two nodes (B and C). Of the six derivative relations, four (AC, CA, BD, and DB) are comprised of stimuli separated by one node and will be referred to as one-node derivative relations. The first two are mediated by the nodal stimulus (B), whereas the second two are mediated by the nodal stimulus (C). The remaining two derivative relations (AD and DA) contain stimuli separated by two nodes and will be referred to as two-node derivative relations. To what extent will the number of intervening nodes influence the stimulus control exerted by the derivative relations? Fields et al. (1984) and Fields and Verhave (1987) proposed that the relatedness of two stimuli that constitute a derivative re-

lation in an equivalence class should be an inverse function of the number of nodes that characterize the relation. This postulated relationship has been called the associative distance effect.

Some data reported in studies of equivalence class formation conducted by Lazar, Davis-Lang, and Sanchez (1984) and Sidman et al. (1985) suggest that multinodal derivative relations begin to acquire control after one-node derivative relations have begun to exert stimulus control. Saunders, Wachter, and Spradlin (1988) noted that, for some subjects, the proportion of derivative relations that exerted a high criterion level of control was inversely related to the number of intervening nodes. Although supportive, these data are fragmentary because the studies were not designed to assess the effects of nodality. They did not illuminate changes in degree of stimulus control during the induction process. Furthermore, because control was measured repeatedly for only one derivative relation at a time, it was not possible to measure concurrently the relative degree of control exerted by different derivative relations. The purpose of the present investigation was to ascertain how the number of intervening nodes in derivative relations influences the degree of stimulus control exerted by these relations. Stimulus control exerted by one- and two-node derivative relations was measured concurrently while establishing four-member equivalence classes.

METHOD

Subjects

Seven female Queens College students (5 undergraduate, 2 graduate) were recruited from introductory and advanced psychology courses. None had any familiarity with the research area. Their ages ranged from 18 to 25 years. The undergraduate subjects received partial course credit upon completion of the experiment. Credit, however, did not depend upon subjects' performance during the experiment. The graduate students merely volunteered their time. Subjects participated in one or two sessions per week over the course of 2 to 3 weeks. Sessions ranged in length from 1.0 to 1.5 hr.

Apparatus

The experiment was conducted using an MS-DOS® compatible microcomputer with a monochrome monitor. The subject sat facing the computer monitor with the keyboard at hand. All stimuli were presented on the monitor. All responses involved pressing various keys on the computer keyboard. The experiment was conducted using software developed for that purpose. All data collection was automated.

Table 1

The nonsense syllables used as stimuli in the experiment, as well as their symbolic representations depicted in letter-number notation.

Class 1		Class 2	
A1	GEQ	A2	HEV
B1	HUK	B2	GUQ
C1	POV	C2	ZOJ
D1	SEJ	D2	PEF

The eight nonsense syllables listed in Table 1 were used as sample and comparison stimuli during the experiment. Each stimulus is represented symbolically by a unique combination of a letter and a number in which the number designates class membership and the letter designates a unique stimulus within a class (Fields et al., 1984).

Procedure

Instructions. At the start of the experiment, the subject was shown the following instructions on the computer monitor.

Thank you for volunteering to be a subject in this experiment. PLEASE DO NOT TOUCH ANY OF THE KEYS ON THE KEYBOARD YET. In this experiment you will be presented with many trials. Each contains three CUES, these will be common words, or three letter nonsense words such as ZEQ or WUV. YOUR TASK IS TO DISCOVER WHICH WORDS GO TOGETHER.

Initially there will also be INSTRUCTIONS that tell you how to respond to the cues, as well as LABELS that will help you to identify the cues on the screen. The labels and the instructions which tell you which KEYS to press will slowly disappear. Your task will be to RESPOND CORRECTLY to the CUES and the INSTRUCTIONS by pressing a key on the computer's keyboard. The experiment is conducted in phases.

If you want to take a break at the end of a phase, please call the instructor. When you are ready to start, press the key with either the word ENTER or RETURN written on it.
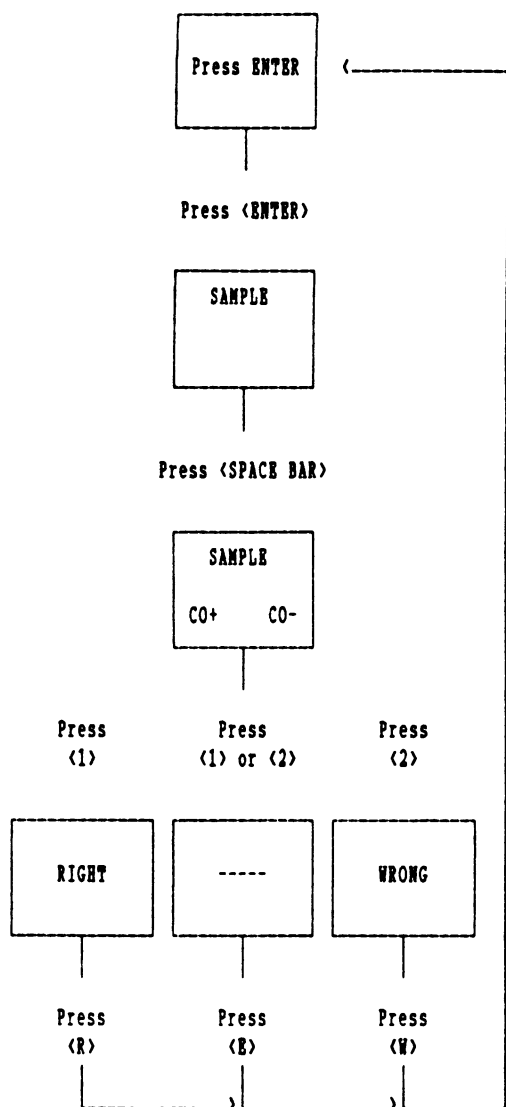
Fig. 2. The sequence of stimulus configurations and response contingencies that were scheduled in each trial of the experiment.

Trial structure. All training and testing were conducted on a trial-by-trial basis using the conditional discrimination paradigm. Three stimuli were presented on each trial. The sample (Sa) and the positive comparison (Co+) were chosen from one class and were presented along with a negative comparison (Co−) chosen from the other class. For a given stimulus triad, the stimulus used as the sample was never used as a positive comparison, and vice versa. On each trial, the stimuli were displayed in an isosceles triangular array on the monitor

with the sample at the vertex of the triangle and the comparisons at the corners of the base.

Trial contingencies and responses within a trial. Trial contingencies and responses that could occur within each trial are illustrated in Figure 2. Each trial began when the message "Press ENTER" appeared on the screen. Once the subject pressed the "ENTER" key, the message disappeared and the sample was displayed. When the subject pressed the space bar in the presence of a sample, both comparisons were added to the screen display. (Pressing the space bar is a nondifferential observing response; Constantine & Sidman, 1975.) The subject then chose one of the comparisons by pressing the "1" key or the "2" key. The "1" key was pressed to select the comparison presented on the left, and the "2" key was pressed to select the comparison presented on the right. Either choice cleared all stimuli from the screen and produced a feedback message. If the Co+ was chosen, the message "RIGHT" appeared on the screen and remained there until the subject pressed the "R" key. If the Co− was chosen, the message "WRONG" appeared on the screen and remained there until the subject pressed the "W" key. If noninformative feedback was scheduled, the letter "E" appeared as soon as the subject emitted either of the choice responses and remained there until the subject pressed the "E" key. The screen was then cleared momentarily, after which the message "Press ENTER" reappeared and initiated the next trial. On test trials, either choice response produced only the noninformative letter "E" as feedback. (A series of two-choice conditional discrimination trials were used to inform the subjects that "E" stood for "NO INFOR-MATION" prior to its first use. In this manner, they were informed that "E" did not mean "Error.") The results of pilot work indicated that requiring observing responses to the sample and feedback stimuli presented in each trial facilitated the establishment of stimulus control exerted by the conditional relations.

Stage 1: Preliminary training. To negotiate all trials satisfactorily, the subject had to emit a variety of keyboard responses in the presence of the different stimuli that were presented in each trial. In Stage 1, the appropriate keyboard responses were brought under the control of the cues presented on each trial. Common words with clear relations were used as

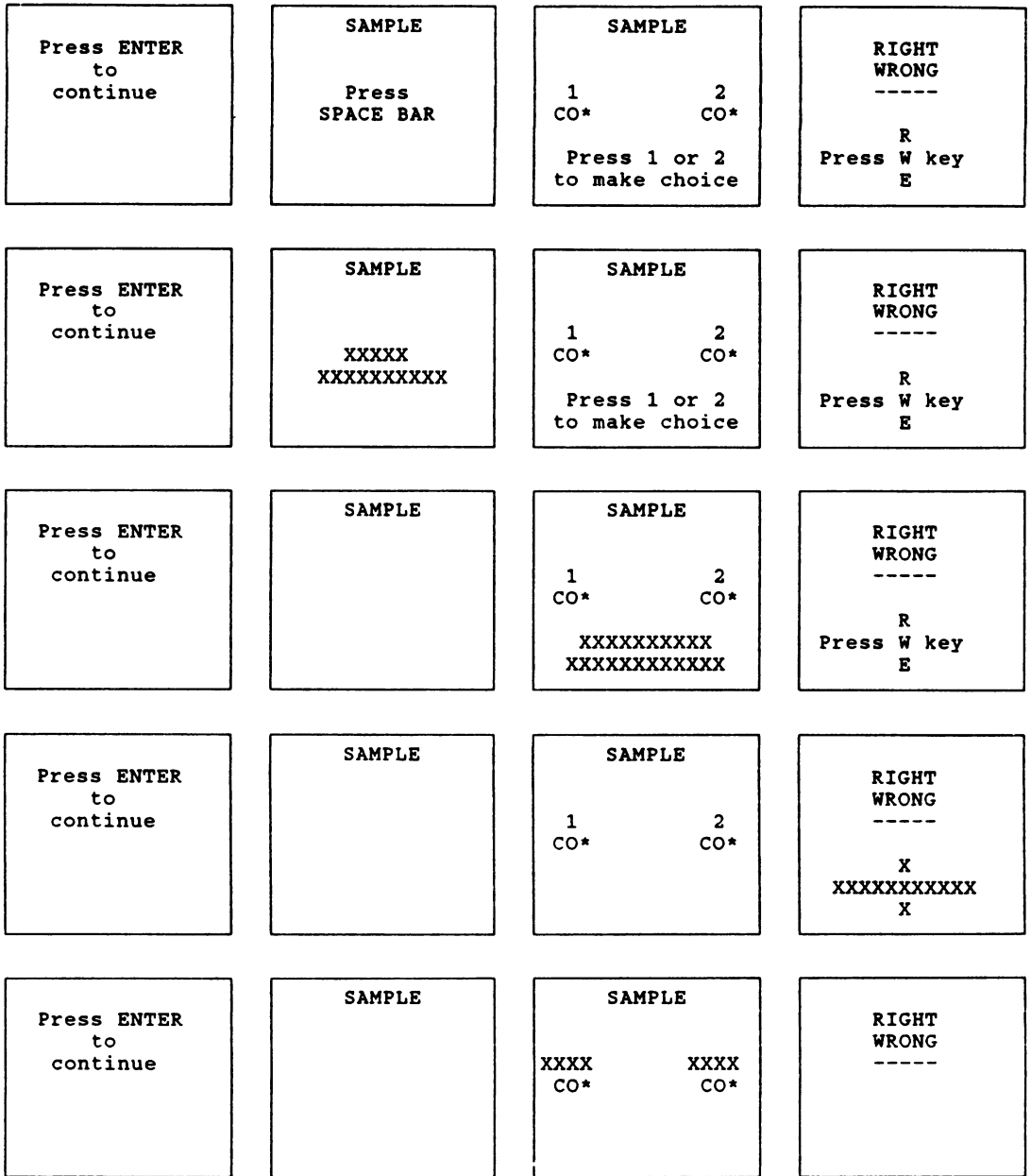|			
Press ENTER to continue	SAMPLE Press SPACE BAR	SAMPLE 1 2 CO* CO* Press 1 or 2 to make choice	RIGHT WRONG ----- R Press W key E
Press ENTER to continue	SAMPLE XXXXX XXXXXXXXX	SAMPLE 1 2 CO* CO* Press 1 or 2 to make choice	RIGHT WRONG ----- R Press W key E
Press ENTER to continue	SAMPLE	SAMPLE 1 2 CO* CO* XXXXXXXXX XXXXXXXXXXX	RIGHT WRONG ----- R Press W key E
Press ENTER to continue	SAMPLE	SAMPLE 1 2 CO* CO*	RIGHT WRONG ----- X XXXXXXXXXX X
Press ENTER to continue	SAMPLE	SAMPLE XXXX XXXX CO* CO*	RIGHT WRONG -----

Fig. 3. Fading of instructional prompts. Each box indicates a screen display. The boxes on a given row indicate the series of screen displays presented in a trial from onset (on left) to termination (on right). Each successive row indicates the elimination of one instructional prompt. The prompt that was deleted is indicated by Xs. The actual displays did not have Xs; they are used here to highlight the prompt that was deleted.

samples and comparisons; this made the choice of the correct comparison obvious to our subjects. In addition, five brief instructional prompts appeared on the computer screen with the samples and comparisons, as illustrated in Figure 3. The instructional prompts described the specific responses that were to be emitted in the presence of each screen display. The top row of Figure 3 illustrates the sequence of screen displays that occurred within a trial with all prompts present. After every third consecutive correct trial, one prompt was de-
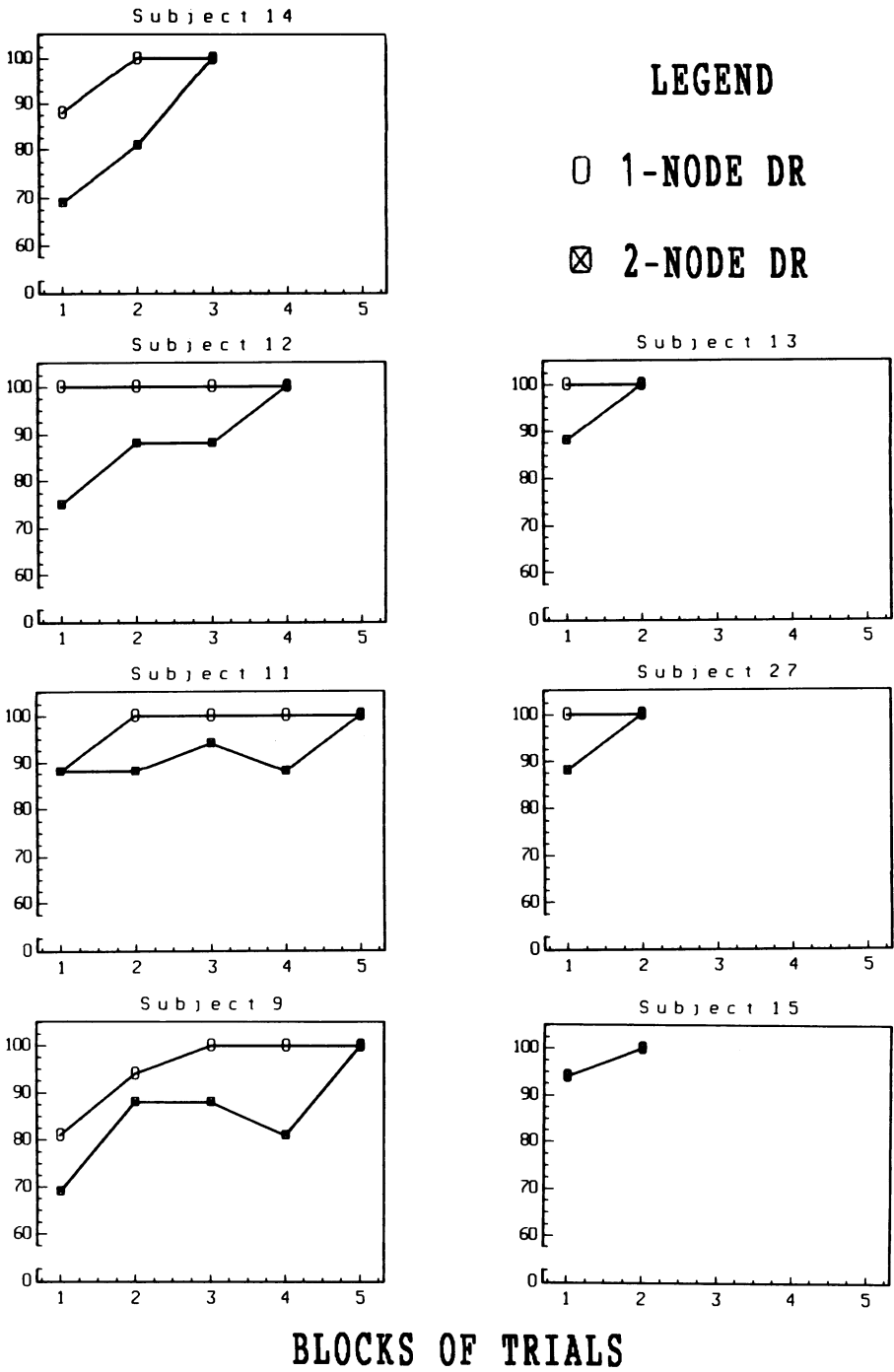
Fig. 4. Degree of stimulus control exerted by the new one- and two-node derivative relations induced after CD training. Data are plotted as a function of test blocks. Each graph contains data for 1 subject.

leted. The sequence in which the prompts were deleted and the appearance of all screen displays within a trial as each prompt was deleted are illustrated in successive rows of Figure 3 (Fields, 1980). At the end of Stage 1, the stimuli in a trial were presented without prompts. Stage 1 was completed once performance exceeded 85% accuracy (14 of 16 correct trials) during a single block.

For the remainder of the experiment, if a keyboard error was made, the instruction relevant to that error reappeared on the screen for that trial and for the next two trials; it was then eliminated until the error reoccurred.

Stage 2: Establishment of the conditional relations AB and BC. After eliminating the response prompts, the two-term conditional relations (A1-B1 and A2-B2) were trained. The first relation was the precursor of Class 1; the other was the precursor of Class 2. The stimulus triads used for training are listed in Table 2. For each stimulus triad, the positive comparison appeared once on the left and once on the right to counterbalance for position effects. This yielded a total of eight triads, which were repeated once for a total of 16 trials in a block. All trials in a block were presented in a random order without replacement. A block was repeated until all 16 triads were responded to correctly. Once the mastery criterion was reached (100% correct choices for all trials in a block), a second two-term relation was established by training the B1-C1 and B2-C2 conditional discriminations using the stimulus triads listed in Table 2. Initially, the BC relations were intermixed with AB relations in a 3:1 ratio of new to old material for a total of 16 trials. Training continued until the mastery criterion was reached. After the establishment of the criterion level of control by the AB and BC relations, the percentage of trials followed by informative feedback was reduced from 100%, to 75%, to 25%, then to 0% during successive blocks of Stage 2, as long as the performance within a block was maintained at 100% accuracy. During the reduction of informative feedback, trial blocks contained BC and AB relations in a 1:1 ratio for a total of eight trials.

Stage 3: Testing control by emergent relations after AB and BC training. The establishment of the AB and BC relations potentially formed two three-member classes (A → B → C). This

Table 2

Symbolic representation of the stimulus triads used in each experimental stage.

Stage 2. Establish AB and BC relations by training

Sa	Co+	Co−
A1	B1	B2
A2	B2	B1
B1	C1	C2
B2	C2	C1

Stage 3. Test for control by emergent relations

New one-node derivative relations		
A1	C1	A2, C2
A2	C2	A1, C1
C1	A1	A2, B2, C2
C2	A2	A1, B1, C1

New symmetrical relations		
B1	A1	A2, B2
B2	A2	A1, B1
C1	B1	A2, B2, C2
C2	B2	A1, B1, C1

Stage 4. Establish CD relations by training

C1	D1	D2
C2	D2	D1

Stage 5. Test for control by emergent relations

New symmetrical relations		
D1	C1	B2, C2
D2	C2	B1, C1

New one-node derivative relations		
D1	B1	B2, D2
D2	B2	C1, D1
B1	D1	A2, D2
B2	D2	A1, D1

New two-node derivative relations		
A1	D1	C2
A2	D2	C1
D1	A1	A2, B2
D2	A2	A1, D1

Old symmetrical relations		
B1	A1	A2, B2
B2	A2	D1
C1	B1	A2
C2	B2	A1

Old one-node derivative relations		
A1	C1	C2
A2	C2	A1
C1	A1	A2, C2
C2	A2	A1

was assessed by measuring the stimulus control exerted by all symmetrical and derivative relations for both classes. Symmetrical, transitive, and equivalence relations were presented with the training relations concurrently. This block of trials is referred to as an STE test. For some subjects, STE blocks contained training and test relations in a 1:1 ratio for a total of 80 trials. Here, each test relation appeared with each Co− shown in Table 2. Other subjects received STE blocks containing 16 test relations and 96 training relations. In these blocks, each test relation appeared with one Co− that was selected randomly and varied from block to block. These two blocks were used to examine the effect of the proportion of training relations to emergent relations on class formation. The trials within a block were presented in a random order. All trials were followed by noninformative feedback. This block was repeated until all relations exerted the criterion level of control (100% accuracy) or for a maximum of three blocks. If all of the emergent relations did not reach the criterion level of control after three blocks of trials, a serial assessment protocol was introduced.

In this protocol, each type of emergent relation was presented alone until it came to exert the criterion level of stimulus control. Again, all choices were followed by noninformative feedback. The order of serial assessment was equivalence relations (CA), symmetrical relations (BA), equivalence relations (CA), symmetrical relations (CB), equivalence relations (CA), transitive relations (AC), and equivalence relations (CA). Throughout the serial assessment, emergent relations were presented along with training relations in a 1:1 ratio. The length of trial blocks varied from 28 to 44 depending on the type of emergent relations that was tested. If criterion level performance did not occur on the first set of equivalence probe blocks, the subject advanced to the BA symmetrical relation probes. A subject did not advance to the next set of equivalence probe blocks until the BA symmetrical relations came to exert the criterion level of control. This pattern was maintained throughout serial assessment; failure of the equivalence relations to gain control of responding on a given set of blocks was followed by assessment of the other symmetrical relations (CB) and then the transitive relations (AC). In this manner, blocks of equivalence relation (CA) probe trials were

interwoven with blocks of BA, CB, and AC probe trials. As soon as the equivalence relations came to exert the criterion level of control, serial assessment was terminated. Additional blocks of the concurrent test of stimulus control by all relations (the STE test) were then reintroduced. At this point, all subjects received blocks of 32 trials, with training and test relations in a 1:1 ratio. Each test relation was presented with one Co− that was selected randomly and varied from block to block. The formation of the three-member equivalence classes was confirmed by demonstrating that the emergent relations presented in the concurrent STE test exerted the criterion level of stimulus control.

In each test configuration, sample stimuli were presented in combination with negative comparisons not used in training, as dictated by complementarity. To rule out interpretations of choice of Co+ based on valence disparity, derivative relations that had positive and negative comparisons of equal valence (neutral tests) were used (Fields et al., 1984).

Stage 4: The establishment of the conditional relation CD. The four-member classes were potentially formed by adding D to A → B → C by training the CD relation, as illustrated in Table 2. The CD relation was presented along with AB and BC in a ratio of 3:1:1 in blocks of 20 trials. Although the same stimulus configurations were presented, the percentage of feedback was reduced again from 100%, to 75%, to 25%, to 0% in successive blocks as long as performance was maintained at 100% accuracy. During the reduction of informative feedback, trial blocks contained the CD, AB, and BC relations in a 1:1:1 ratio for a total of 12 trials. The structure of the four-member class established in Stage 4 was A → B → C → D.

Stage 5: Testing control by emergent relations after CD training. Once all training relations controlled responding at the criterion level, control exerted by all of the new derivative relations (AD, DA, BD and DB), and the symmetrical relations (DC) was evaluated concurrently, under noninformative feedback conditions and in the absence of training trials, as illustrated in Table 2. The new test relations were presented along with the symmetrical and derivative relations that had been presented after the establishment of the three-member classes. They are referred to as the old sym-

metrical and one-node derivative relations in the Stage 5 section of Table 2. The test trials were presented repeatedly until all emergent relations presented in a block exerted the criterion level of stimulus control or until a maximum of six blocks of 72 trials had been presented. Each block contained 18 different emergent relations, each presented four times. For relations that appear with two negative comparisons in Table 2, each Co− was used twice; for relations that appear with only one Co−, that Co− was used four times. This was a by-product of the random selection of negative comparisons. In each block, all emergent relations were presented in a random order without replacement. The complementarity and valence considerations mentioned in the description of Stage 3 also held for the stimulus configurations that were used in this stage of the experiment.

RESULTS

During Stage 1, trial stimuli were presented with instructional prompts that indicated the keys to be pressed during the trial. At the start of training, correct responding almost always occurred immediately, demonstrating the stimulus control exerted by the prompts. Stimulus control was calculated as the percentage of choosing the Co+. As these response-controlling prompts were eliminated successively, correct responses continued to occur to each of the stimuli presented within each trial. Thus, the fading of the prompts helped to transfer the control of all keyboard responses from the instructional prompts to the samples, comparisons, feedback, and intertrial interval stimuli in each trial. This entire process occurred with no more than one error per subject.

Table 3 summarizes the number of blocks required for each subject to complete AB and BC training in Stage 2. The acquisition of stimulus control during AB and BC training occurred rapidly, averaging 2.4 and 2.0 blocks, respectively. The few errors that occurred did so during the first blocks. Stimulus control was maintained as the percentage of informative feedback was reduced to zero. The fact that so few blocks were needed to train the AB and BC relations as well as to reduce the degree of informative feedback to zero demonstrates that stimulus control was maintained with each change in experimental condition.

During Stage 3, all symmetrical, transitive, and equivalence relations were presented concurrently (the STE test). The criterion level of stimulus control was not reached for 5 subjects (see Table 3). The proportion of training to test relations did not influence the stimulus control exerted by the emergent relations. Subsequent testing with each emergent relation using the serial assessment protocol resulted in the development of stimulus control by each relation. The number of blocks needed to complete Stage 3 varied among subjects (Table 3). Stimulus control was maintained by all of the emergent relations during the second STE test, as illustrated in Table 3.

During Stage 4, the establishment of control by the CD relations occurred rapidly, averaging 1.7 blocks (see Table 3). During Stage 5, stimulus control was assessed for all of the new symmetrical and derivative relations created by the addition of D to the A → B → C class. For all subjects, the emergent relations gained the criterion level of control. The number of blocks required by each subject to reach criterion is indicated in the last line of Table 3. These data demonstrate that four-member classes had been formed successfully.

Table 4 lists the relative frequency with which subjects chose the positive comparisons in each new one- and two-node derivative relation. For each subject, the data for each derivative relation are presented separately for each test block in Stage 5. In general, the one-node derivative relations exerted 100% control in more blocks than did the two-node derivative relations. Thus, on a global level, the data support the notion that stimulus control exerted by derivative relations is inversely related to nodality. If so, a one-node derivative relation drawn from a given class in a given block for a given subject should exert more stimulus control than a matched two-node derivative relation. This hypothesis was tested descriptively by comparing all of the matched pairs (Table 4) in which the stimulus control values exerted by the one- and two-node derivative relations were unequal. (These matches are the values printed in bold face in Table 4.) To illustrate with Subject 14, in Test Block 1 stimulus control exerted by the one-node derivative relation D2-B2 was compared to the control exerted by the two-node derivative relation D2-A2. In 22 of 25 cases, the one-node derivative relation exerted more con-

Table 3

Number of blocks needed to complete each stage of the experiment for each subject. A–D refer to stimuli used in two-term relations, Conc STE refers to concurrent testing for control with training, symmetrical, transitive, and equivalence relations. Serial E, S, E, T, E refers to the serial assessment and induction of control by the emergent relations. Asterisks indicate failure to meet the criterion of stimulus control.

| Stage | Condition | % feed-back | Trials/ block | Number of blocks | | | | | | | Aver-age |
				S9	S11	S12	S13	S14	S15	S27	
1	Fade prompts	100	16	1	1	1	1	1	1	1	1.0
2	Training										
	AB	100	16	2	3	3	2	3	2	2	2.4
	AB + BC	100	16	3	3	2	2	1	2	1	2.0
	AB + BC	75	8	1	1	1	1	2	3	1	1.4
	AB + BC	25	8	3	1	1	1	1	1	1	1.3
	AB + BC	0	8	1	1	1	1	1	1	1	1.0
3	Testing										
	Conc STE	0	80–112[a]	3*	3*	2	3*	4	3*	3*	—
	Serial E, S, E, T, E	0	28–44	16	55	NA	28	NA	41	2	—
	Conc STE	0	32	2	2	NA	1	NA	4	2	2.2
4	Training										
	CD + AB + BC	100	20	6	1	1	1	1	1	1	1.7
	CD + AB + BC	75	12	1	1	1	1	1	1	1	1.1
	CD + AB + BC	25	12	2	1	1	1	1	1	1	1.1
	CD + AB + BC	0	12	1	1	1	1	1	1	1	1.0
5	Testing										
	Conc STE	0	72	5	5	2[b]	1[b]	3	2	1[b]	—

[a] The length of this test block varied from 80 to 112 because different subjects received different proportions of training and testing relations.

[b] These blocks are each divided into blocks of 36 trials for purposes of computing relative frequency of choice responding listed in Table 4.

trol than the two-node derivative relation. This analysis, however, does not capture the changes in stimulus control exerted by one- and two-node derivative relations with their repeated presentation for each subject.

These changes were analyzed by calculating the relative frequency of choosing the positive comparisons averaged for all of the new one- and two-node derivative relations in each testing block of Stage 5. These data, listed in the rightmost columns of Table 4, are plotted as a function of blocks for individual subjects in Figure 4. Initially, the derivative relations did not exert the criterion level of control. With repeated presentations, however, accuracy of responding increased and eventually reached 100%. Thus, stimulus control exerted by the new derivative relations increased during successive blocks of testing. We then compared the control exerted by the new one- and two-node derivative relations that were formed

when the four-member classes were established. At the start of testing in Stage 5, the one-node derivative relations exerted more control than the two-node relations for 5 of 7 subjects. Stimulus control was inversely related to nodality. With continued testing, the overall level of control increased and the disparity between the control exerted by one- and two-node relations decreased. In the last phase, all derivative relations came to exert the criterion level of stimulus control. For Subject 11, one- and two-node derivative relations exerted the same level of control initially. Beginning with the second block, however, control was inversely related to nodality. By the fifth test block, both relations exerted the criterion level of control. Finally, for Subject 15, the initial levels of stimulus control were so high that disparities between control exerted by one- and two-node derivative relations were nonexistent.

Table 4

Percentage of choice of the positive comparison in Stage 5 tests of stimulus control for one- and two-node derivative relations.

Subject	Block	Nodes	B1D1 A1D1	B2D2 A2D2	D1B1 D1A1	D2B2 D2A2	One node	Two nodes
14	1	1	100	100	100	100	100	
		2	75	50	75	75		69
	2	1	100	100	100	100	100	
		2	75	100	75	75		81
	3	1	100	100	100	100	100	
		2	100	100	100	100		100
12[a]	1	1	100	100	100	100	100	
		2	100	100	100	0		75
	2	1	100	100	100	100	100	
		2	100	100	100	50		88
	3	1	100	100	100	100	100	
		2	100	100	100	50		88
	4	1	100	100	100	100	100	
		2	100	100	100	100		100
11	1	1	100	100	50	100	88	
		2	100	100	50	100		88
	2	1	100	100	100	100	100	
		2	75	75	100	100		88
	3	1	100	100	100	100	100	
		2	75	100	100	100		94
	4	1	100	100	100	100	100	
		2	100	50	100	100		88
	5	1	100	100	100	100	100	
		2	100	100	100	100		100
9	1	1	100	75	75	50	75	
		2	25	75	75	100		69
	2	1	100	100	75	100	94	
		2	100	75	100	50		81
	3	1	100	100	100	100	100	
		2	100	100	75	50		81
	4	1	100	100	100	100	100	
		2	100	100	100	25		81
	5	1	100	100	100	100	100	
		2	100	100	100	100		100
13[a]	1	1	100	100	100	100	100	
		2	100	50	100	100		88
	2	1	100	100	100	100	100	
		2	100	100	100	100		100
27[a]	1	1	100	100	100	100	100	
		2	100	100	100	50		88
	2	1	100	100	100	100	100	
		2	100	100	100	100		100
15	1	1	100	75	100	100	94	
		2	100	100	75	100		94
	2	1	100	100	100	100	100	
		2	100	100	100	100		100

[a] Indicates blocks of 36 trials.

DISCUSSION

Three-member equivalence classes were formed by training AB and BC. After testing for control by the emergent relations, a fourth stimulus, D, was linked to the A → B → C class by conditional discrimination training with CD. The existence of the two four-member classes (A → B → C → D) was assessed by measuring the control exerted by the new one- and two-node derivative relations concurrently. When testing began, the degree of control exerted by the one- and two-node derivative relations was inversely related to the number of nodes that separated the two stimuli that constituted each derivative relation. As stimulus control exerted by the derivative relations increased, the disparity between the control exerted by the one- and two-node derivative relations decreased. Eventually, all derivative relations came to exert complete stimulus control. These results demonstrate that the degree of control exerted by derivative relations was inversely related to nodal distance while the relations gained stimulus control. Such results confirm the associative distance effect postulated by Fields et al. (1984) and Fields and Verhave (1987). The data of the present experiment also demonstrate that the control exerted by a derivative relation is determined jointly by the number of times it has been presented and by the nodality of the relation. Specifically, the control exerted by a derivative relation is inversely related to the number of nodes that characterize the relation and directly related to the number of presentations of that derivative relation. Our results, therefore, refine the current view of the manner in which equivalence classes develop. At least one structural variable, nodality, which partially defines the organization of an equivalence class, along with a functional variable, number of test trial presentations, influences the development of equivalence classes.

Are there alternative explanations of the nodal distance effect? Here we will consider language mediation. It has been suggested that equivalence classes can be established only if subjects are "language-able" (Devany, Hayes, & Nelson, 1986; Hayes, 1989; Sidman et al., 1982). To what extent might verbal mediation account for our data? Assume that the subjects memorized the verbal equivalents of the eight stimuli in the two classes as well as their order

of introduction. Further, assume that the subjects rehearsed the memorized list to determine which comparison was a member of the same class as the sample. The memorized rehearsal lists would accurately specify the appropriate stimuli and their order of introduction. Therefore, a subject's choice accuracy should be 100% for each relation, and all relations should exert complete control on the first and all subsequent test trials. Both of these predictions are contrary to the outcome of our experiment. Therefore, a verbal mediation account is not viable.

Formal Similarities of Nodality to Other Research Areas

When an equivalence class is formed, some stimuli become related as a result of direct training. Other stimuli become related indirectly through the mediation of nodal stimuli. These stimulus pairs have been called derivative relations (Fields & Verhave, 1987). The degree of stimulus control exerted by these relations is inversely related to the number of intervening nodes. There are other areas of research that have studied the relatedness of stimuli in groups, where the stimuli did not become related by direct training. We will consider serial learning and remote associations, semantic memory networks, and the field of transitive inference.

Serial learning. The relatedness of nonadjacent stimuli, or remote associations, in serial learning lists was studied experimentally by Ebbinghaus (1885/1964) in his derived list experiments. Ebbinghaus concluded that the associative strength of nonadjacent stimuli in a serial list was inversely related to the number of intervening stimuli. Hull (1935), Lepley (1934), and Bugelski (1950) noted that nonadjacent stimuli in a serial list separated by more stimuli are also separated by longer intervals. Of the two confounded variables, they proposed that associative strength was inversely related to the temporal separation rather than to the number of intervening stimuli. This can be viewed as a temporalized version of the "doctrine of remote association." More recent serial learning experiments have been conducted to demonstrate the influences exerted by time and number of nodes (Bäumler, 1974; Dallett, 1965; Johnson, 1975; Johnson, Jamieson, & Curry, 1976; Slamecka, 1964, 1985). As long as serial learning paradigms are used, the effects of nodality will be con-

founded with temporal factors, a problem that does not exist in the current experiment. The use of the conditional discrimination paradigm and the presentation of all training relations in a randomized order mean that time is not a variable that characterizes derivative relations. Therefore, the results of the current experiment cannot be attributed to temporal separation. Our data, then, provide an unambiguous demonstration of the effects of nodal distance.

Semantic memory networks. Another area that bears formal similarities to our research is that of semantic memory networks or knowledge structures (Anderson, 1976, 1981; Collins & Loftus, 1975; Collins & Quillan, 1969). A semantic memory network consists of a group of concepts that are interrelated, both directly and indirectly. In addition, each concept contains many concept-defining features. The concepts function as nodes connected by links that reflect their logical interrelations. Additionally, the features of a given concept are linked to that particular concept/node just as "singles" are affixed to nodes in our structural analysis of equivalence classes (Fields & Verhave, 1987). In a semantic memory network, then, two indirectly related concepts are connected via yet other concepts that function as semantic nodes. Likewise, a concept and the particular feature of another indirectly related concept are connected through other intervening conceptual nodes. Finally, it is assumed that activation of one node spreads in a decremental fashion to other nodes within the network, where the degree of activation is inversely related to nodal distance. In general, the data indicate that the relatedness of remote terms in a particular semantic memory network is inversely related to the nodal structure of the network. Thus, there are formal similarities in the structures of equivalence classes and semantic memory networks. Also, nodality influences the functional relatedness of stimuli in both domains. A similar case can be made for the study of transitive inference (Breslow, 1981; Bryant & Trabasso, 1971; Thayer & Collyer, 1978).

General Conclusions

The formal similarities that exist between equivalence classes and semantic memory networks in structure and function suggest that bridges can be established between these research domains. This possibility, however, must be tempered by the fact that many differences exist between the study of equivalence classes, semantic memory networks, and development of transitive inference. These differences include the experimental designs that are used, the nature of the relations that link the terms in each domain, the types of stimuli that are used to study each phenomenon, and the measurement procedures used to assess the relatedness of stimuli. The same can be said for equivalence classes and serial learning phenomena. Before any conclusions can be drawn regarding substantive similarities, the apparent differences must be reconciled theoretically and conceptually. Only then can carefully designed bridging experiments be conducted to identify the actual points of contact that may exist between these research domains.

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